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RELATION OF TUBER MATURITY AND OF STORAGE FACTORS TO POTATO DORMANCY

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FOREWORD

Though the buds on a newly harvested potato tuber do not grow for sometime after the whole or a part of it is planted, even under conditions favorable for growth, they sprout rapidly after the tuber has been held in storage for a period of from a few weeks to several months. The time after harvesting during which these buds will not sprout, or do so very slowly, is called the dormant period. The causes of the inception of this condition are unknown. Schmid(17) and Appleman(3) suggested that its continuance is largely due to a lack of oxygen in the internal tissues. Appleman showed that when the periderm was removed, or when oxygen was introduced by other means, sprouting of dormant tubers was hastened.

Knowledge of the conditions causing dormancy, and of methods for shortening or "breaking" the dormant period, are of practical value. The growing season in California and in the southern states is long enough to produce two crops of potatoes yearly. To do this economically, it is necessary to use tubers produced by the early or spring crop, as seed for the late or fall crop. The period intervening between the two crops is so short, however, that the dormancy of the spring crop tubers often results in slow and irregular sprouting, if they are used for planting the fall crop. Another aspect of the dormancy problem is in connection with storage of table or seed potatoes, where it is desired to continue the dormant condition as long as possible.

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Work on potato dormancy was begun at Davis, California, in 1922. In the years since, much data have been accumulated. Many of the experiments, however, were of a preliminary nature, and have not been followed up intensively, because other methods of treatment seemed more promising. Some of the results obtained with chemical stimulants have been reported elsewhere by Rosa[15, 16] In this paper will be given the results of some of the experiments on certain phases of the problem, dealing with the behavior of potato tubers in relation to their maturity and their storage environment. No attempt is made to give results of the effect of the various treatments upon yield; the field experiments have not been extensive enough to give reliable data on this point. It may be assumed, however, that treatments which result in more rapid sprouting and in a higher percentage of germination, will increase the yield of both spring and fall crops, but especially of the latter, for which the growing period is usually cut short by frost.

Materials and Methods

Two varieties, White Rose and Idaho Rural, have been used in most of the experiments. The first, which is the most important commercial variety in California, is also known here as Wisconsin, Wisconsin Pride, and Great Divide, and in the East as American Giant and Empire State. The second variety is little grown in California but is much used in the Pacific Northwest, where is its also known as Charles Downing and Earliest of All. A third variety, Irish Cobbler, was included in a few experiments. It has a long dormant period, which is difficult to break, while the White Rose and Idaho Rural varieties have short, easily broken dormant periods. Tubers grown at the University Farm, both in spring and fall crops, have been used. Experimental plantings have been made in soil in the field, and in sand in coldframes and in the greenhouse. The first method represents ordinary practical conditions, while the second and third allow better control of moisture and temperature. The tubers or seed pieces, which are hereafter referred to as "sets," were planted about 3 inches deep. Cut sets averaging about 30 grams in weight were used in all tests, unless otherwise specified. Counts were made every three or four days of the sprouts as they appeared above the surface of the soil.

In the calculation of results, the arrival of the sprouts above ground is referred to as emergence. The best index of the speed of sprouting is the average number of days required after planting for

the sprouts to reach the surface of the soil. This numerical index is low when sprouting is rapid and high when sprouting is slow. The proportion of the sets planted, which produced plants, is referred to as "per cent stand."

Relation of Tuber Maturity to Dormancy

In 1925, samples were dug at 10-day intervals from the spring crop of White Rose and Idaho Rural, in 1926 of Idaho Rural, and in 1927 of White Rose, Idaho Rural, and Irish Cobbler. The first sample was dug as soon as tubers large enough for cut sets were available. At this harvest, as well as at the second, the plants were fully green and plants and tubers were growing rapidly. At the third and fourth harvests, the plants were showing signs of maturity, with some of the leaves dead. At the fifth harvest (in 1926 and 1927) the tops were completely dead. The tubers increased in size and in maturity during this period. Only at the last harvest in each year was the skin suberized sufficiently so that it did not rub off easily. Each sample was divided, one part being placed in cold storage at 4° Centigrade, the other in a celler at 23° C, except in 1927, when cellar storage alone was employed. The samples were held until July 26 in 1925, July 14 in 1926, and July 27 in 1927, when they were removed from storage, cut and planted. Thus in 1925 the storage period for the first sample was 57 days and for the last, 26 days. In 1926 and 1927 the storage period ranged from 55 down to 15 days. No consistent differences in results were apparent between the halves of the samples stored at 4° and at 23° C, hence the data have been combined, as shown in table 1.

With the White Rose variety in 1925, the percentage of stand seemed to be slightly higher in the samples dug early, but in the other ten series it was higher in the lots harvested late. This was especially true in 1927, with all three varieties, both under coldframe and field conditions. Those sets which did not produce plants, decayed. This decay, which occurs within a few days after planting, is probably caused by fungi which invade the wounded surface of the cut sets. The early harvested, immature tubers in these experiments were rather small. In other tests, it has been noted that where large immature tubers were used, the amount of seed piece decayed was much greater. There is some evidence that cut sets from tubers fully ripened before harvest, are less subject to decay after planting.

With regard to the rate of sprouting, the twelve series of tests were all in agreement. The average number of days required for the

TABLE 1

GROWTH-RESPONSE OF TUBERS HARVESTED AT DIFFERENT STAGES OF MATURITY

	Coldframe planting				Field planting		
	Number of sets planted	Per cent stand	Average number of days to emerge	Average number of stems per set	Number of sets planted	Per cent stand	Average number of days to emerge
White Rose, 1925							
Harvested May 30	60	76.7	37.2	1.15	167	67.7	44.3
Harvested June 10	60	78.3	33.7	1.40	162	63.0	43.8
Harvested June 20	119	73.6	30.0	1.22	172	58.7	35.7
Harvested July 1	60	63.4	25.4	1.58	157	58.6	29.7
Idaho Rural, 1925							
Harvested May 30	59	78.0	47.1	1.13	166	66.2	55.7
Harvested June 10	60	79.3	34.9	1.26	145	61.5	49.6
Harvested June 20	90	80.0	35.6	1.16	172	59.2	39.0
Harvested July 1	60	73.1	37.5	1.33	149	76.5	39.2
Idaho Rural, 1926							
Harvested May 20	60	81.7	37.6	1.10	215	45.0	58.5
Harvested May 30	62	81.9	37.4	1.20	213	45.2	54.8
Harvested June 9	80	90.3	34.1	1.35	207	53.0	48.7
Harvested June 19	333	81.3	33.6	1.36	716	63.3	46.1
Harvested June 29	60	91.6	28.3	1.67	183	64.5	40.4
White Rose, 1927							
Harvested June 2	30	40.0	37.5	1.17	117	62.4	49.5
Harvested June 12	20	3.0	....	....	105	48.6	46.1
Harvested June 22	20	15.0	37.7	1.00	100	28.0	41.6
Harvested July 2	130	72.3	33.5	1.28	577	61.7	34.0
Harvested July 12	30	80.0	25.0	1.46	120	71.6	36.9
Idaho Rural, 1927							
Harvested June 2	30	13.3	38.5	1.00	114	44.7	53.5
Harvested June 12	20	....	....	....	100	42.0	49.0
Harvested June 22	20	30.0	35.2	1.17	112	39.3	42.4
Harvested July 2	90	57.7	35.6	1.15	554	56.5	37.7
Harvested July 30	30	66.6	32.1	1.05	120	74.1	45.8
Irish Cobbler, 1927							
Harvested May 23	30	26.6	43.4	1.00	100	46.0	48.5
Harvested June 2	30	43.3	43.8	1.31	114	64.0	48.2
Harvested June 12	20	25.0	36.0	1.20	119	53.7	41.0
Harvested June 22	20	65.0	38.8	1.15	115	60.8	39.6
Harvested July 2	60	80.0	37.2	1.25	120	78.6	36.2

sprouts to emerge was greatest in the samples harvested earliest, and decreased regularly with the period of harvesting, the time required being shortest in the samples dug most mature. This is somewhat surprising, as the samples dug early had a much longer period in storage before planting. These results probably explain why fall crop potatoes are slow in sprouting when used as seed for the spring crop, a fact noted previously by Rosa[14] and by Martin *et al.*[7] Fall crop

potatoes are harvested immature, as the tops are usually green when killed by frost. Similar results have recently been published by Kolterman,[5] in Germany. He states that the earlier a tuber is separated from its plant, the more time it needs to ripen and to germinate.

The more rapid sprouting of tubers harvested mature in these experiments are not to be considered as opposing the results of Mueller and Molz[8] and of many other investigators, who have found more vigorous plant growth and higher yields with seed tubers harvested immature. In experiments of the latter class, the tubers were stored over winter, ample time being allowed for even immature tubers to reach the end of the dormant period.

The average number of stems arising from each set increased with the maturity of the tubers. This point is of practical importance, for the yield increases with the number of stems to the plant, within limits.

Duration of the Dormant Period

Is the dormant period of definite duration, or is dormancy dissipated gradually? Since the response of tubers harvested immature and fully matured is different, it has to be determined separately on each class of tubers. Samples were harvested July 30 from an April 15 planting of White Rose and Idaho Rural, the plants being almost completely dead at this time, and from the fall crops of the same varieties a few days after the green plants were frosted in November. The tubers in the latter case were nearly full grown but were immature and the skin was easily rubbed off. The tubers were all stored at 20 to 23° C and plantings made at intervals in the greenhouse. The time for sprout emergence for different plantings is shown in table 2.

TABLE 2

Rate of Sprouting of Mature and Immature Tubers Planted at Different Periods After Harvest

Number of days after harvest, planted	Mature tubers Average number of days to emerge		Number of days after harvest, planted	Immature tubers Average number of days to emerge	
	White Rose	Idaho Rural		White Rose	Idaho Rural
6	55.9	77.3	10	84.8	82.7
15	38.2	60.8	15	84.2	74.2
28	20.0	38.4	22	73.8	70.8
39	18.2	30.2	33	43.0	38.4
55	21.2	29.7	43	36.0	32.3
....	....	....	66	29.8	37.5

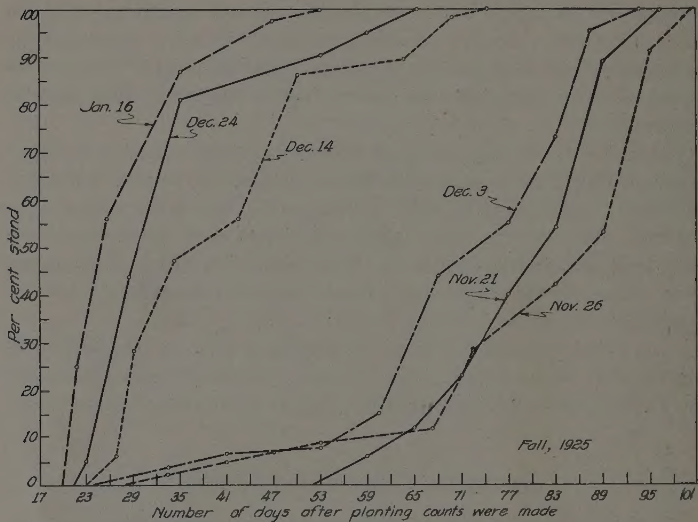

Fig. 1. Rate of sprouting of White Rose potatoes planted at different dates after harvest. Harvested immature, Nov. 11, 1925.

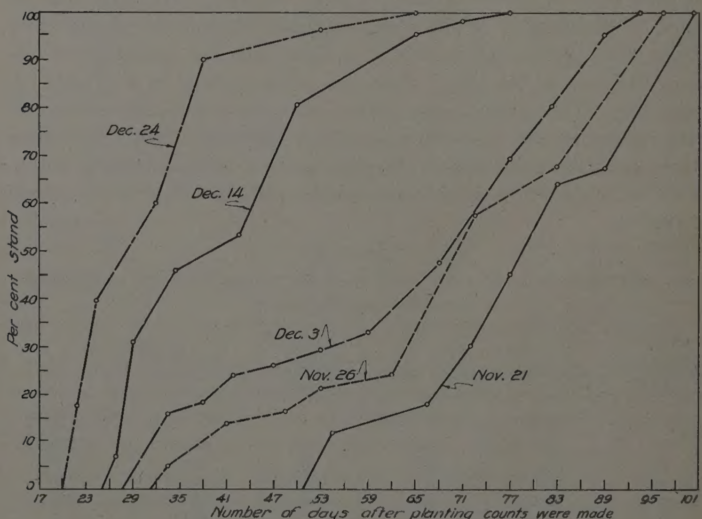

Fig. 2. Rate of sprouting of Idaho Rural potatoes, planted at different dates after harvest. Harvested immature, Nov. 11, 1925.

Although the planting intervals for the two classes of tubers do not correspond exactly, it is easily seen in table 2 that the mature tubers reach a condition where they sprout rapidly, sooner than the immature ones. Thus, mature White Rose tubers may be said to be approaching the end of their dormant period at 28 days, and mature Idaho Rural at 39 days, after harvest. On the other hand, immature tubers of both varieties were still somewhat dormant at the end of 66 days. Emergence from the dormant condition is not abrupt; it is a gradual transition. The rates of sprouting for the immature tubers planted at successive dates are shown in figures 1 and 2. The graphs show that the longer tubers are held after harvest, the sooner do they sprout when planted; furthermore, the later planted tubers all sprout within a relatively short space of time, whereas the sprouting is irregular with tubers planted while still dormant.

It may be concluded that, from a practical point of view, spring crop potatoes to be used as seed for the fall crop should be allowed to become as mature as possible before harvesting, even though the subsequent storage period be very short. Also, it is indicated that when tubers harvested immature are used as seed, the need for the use of stimulants to hasten sprouting is greater than in the case of fully matured ones. Furthermore, immature tubers may be expected to remain unsprouted longer, when stored at ordinary temperatures, than mature ones.

Relation of Storage Temperature to Dormancy

It has been believed generally that placing dormant potatoes in cold storage for a period would result in growth-releasal upon their removal to temperatures suitable for growth. Müller-Thurgau[9] stated that storage of tubers at 0° C shortened the dormant period. His chief experiment involved 10 tubers harvested July 28 and held at 0° C for 40 days, then planted at 20° C. Sprouts formed about three weeks later. In a second test, tubers harvested August 28 were held at 20° C for 10 days, then at 0° C for 16 days longer. The tubers were then planted at 20° C, and formed sprouts within 18 days, a total period of 44 days after harvesting. No control or check lot held at ordinary temperature is mentioned in his report on either experiment. Newton,[11] working at the California Experiment Station, reported that immature tubers stored at 5° C sprouted slightly more rapidly than similar tubers stored at 20° C. His experimental lots, while very small (ten sets per culture), still gave consistent differ-

ences in several plantings made at successive intervals. Stuart[19] also writes: "The effect of the low temperature on the new potato is to shorten the rest period and hasten sprouting."

To test this hypothesis, samples dug June 20 and July 1, 1925, from nearly mature plants were placed in cold storage at 1° C and in a cellar at 23° C. The storage period was 36 days for the June 20 and 26 days for the July 1 samples. The tubers were large and their skin was moderately suberized. They were cut and planted July 26. The plantings were replicated in most cases two or more times. The results of both field and coldframe plantings are given in table 3, the data for samples stored for 36 days and 26 days being combined.

TABLE 3

RELATION OF STORAGE TEMPERATURE TO SPROUTING OF TUBERS HARVESTED NEARLY MATURE, 1925

Variety	Storage temperature	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose	1°C	89	68.0	28.5	172	52.1	35.0
White Rose	23°C	120	70.0	26.5	157	67.8	33.3
Idaho Rural	1°C	60	83.3	36.9	180	65.0	43.0
Idaho Rural	23₀C	120	74.2	36.2	156	71.0	37.1
Irish Cobbler	1°C	30	60.0	57.3	131	52.7	51.3
Irish Cobbler	23°C	30	86.6	44.8	122	62.3	39.0

In five of the six comparisons possible in table 3, the cellar-stored samples gave a higher percentage of stand than the cold-storage ones. In every case, the tubers stored at the higher temperature sprouted somewhat more rapidly than those from cold storage, though in several cases the difference in average number of days to emerge is hardly significant. This result is contrary to the general belief on this point, and contrary to the results of some other investigators. However, the results given here are borne out by the results of most of the later experiments.

In 1926, samples were harvested June 19 from nearly mature plants of two varieties, and were stored at 4°, 8°, 23°, and 30° C. They were cut and planted July 14, after only 25 days in storage. The results are given in table 4.

Storing the Idaho Rural variety at different temperatures seemed to result in no consistent difference in percentage of stand, but with

the White Rose, which was less mature at harvest time, the lots at the two higher temperatures gave a higher percentage of stand than did those in cold storage. There was little difference in time of emergence of the samples stored at 4°, 8°, and 23° C, though the field plantings indicate more rapid sprouting of tubers that had been stored at the higher temperatures. But in all cases those which had been stored at 30° C sprouted much more rapidly than those at lower temperatures. The 30° C storage was in a basement room, heated with electric light globes, the air being constantly stirred by a fan. As the air was drier than that of any of the other storage rooms, the moisture conditions seemed to be the less favorable for sprouting.

TABLE 4

RELATION OF STORAGE TEMPERATURE TO SPROUTING OF POTATOES, 1926

Variety	Storage temperature	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
Idaho Rural	4°C	90	89.2	32.1	208	69.2	42.5
	8°C	55	78.6	33.5	109	56.7	38.6
	23°C	161	76.8	34.6	399	61.6	31.0
	30°C	60	86.6	26.5	106	65.1	31.0
White Rose	4°C	30	63.2	32.3	78	47.5	42.2
	8°C	60	52.6	32.7	106	49.1	39.8
	23°C	60	74.9	34.3	57	58.0	32.1
	30°C	30	86.6	25.1	108	52.2	27.8

In 1927, three varieties were employed for the temperature experiments. The White Rose and Idaho Rural were dug July 6, and stored at the different temperatures from July 8 to July 27, a period of 19 days. The plants were nearly dead at harvest time, and the tubers were fairly well suberized when they were placed in storage. The Irish Cobbler potatoes were fully matured; they were stored for a period of 25 days. The results are given in table 5.

As in previous experiments tubers stored at 22° and 30° gave in most cases a higher per cent of stand than those held in cold storage. This was especially marked in the field planting.

The lot stored at —0° C were in a room supposedly constant for 0° C, but the temperature fell below this point. The exact temperature range for this room is unknown; however some of the tubers stored there were frozen and decomposed promptly upon removal from storage. Over half the tubers did not freeze but remained

sound, though they must have been subject to prolonged under-cooling at below-freezing temperatures. Comparing the germination of these under-cooled tubers to those stored at higher temperatures, it appears that they sprouted somewhat more rapidly. Wright and Peacock[20] report somewhat similar results with under-cooled tubers.

Comparing the lots stored at 4° to those stored at 22° C, it is again seen that sprouting is somewhat slower in tubers that have been stored at the lower temperature. This is true for both coldframe and field plantings of the three varieties used in this experiment. As in the tests of the previous year, however, the difference in sprouting

TABLE 5

RELATION OF STORAGE TEMPERATURE TO SPROUTING OF POTATOES, 1927

Variety	Storage temperature	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose	−0°C	30	90.0	32.5	102	75.4	31.7
	4°C	65	80.4	37.7	118	36.5	34.3
	8°C	30	76.6	34.8	120	40.8	43.2
	22°C	130	72.3	33.6	577	61.7	34.0
	30°C	60	90.0	22.3	238	63.3	24.1
Idaho Rural	4°C	89	86.0	44.3	217	49.6	43.2
	22°C	90	57.7	35.6	554	56.5	37.7
	30°C	60	71.6	24.3	200	63.5	28.9
Irish Cobbler	4°C	29	72.1	42.0	120	42.5	45.0
	22°C	60	80.0	37.2	236	78.6	36.2
	30°C	30	63.3	35.3	120	52.0	35.0

rate between 22° and the lower temperatures are slight, compared to the large difference between 22° and 30°. Tubers that had been stored at the latter temperature sprouted much more rapidly. Figure 3 shows the difference in number of plants above ground, 25 days after planting, in experiments with tubers stored at 4° and at 30° C.

It may be suggested that this striking effect of high temperature upon dormant tubers be due to some direct physical effect, beside the increase in the normal growth rate of the bud primordia and to the increased rate of chemical reactions in the cells associated with higher temperatures. In this connection, it may be noted that Müller-Thurgau and Schneider-Orelli[10] found that exposures of tubers to temperatures of 38°, 40° and 42° C for four to eight hours resulted in an increased respiration rate after their removal to a lower temperature. This indicates an increased oxygen intake by the tubers

after exposure to high temperature, which may be important in connection with increased growth rate. These writers concluded that the effect of heat was fundamentally a weakening of the protoplasm, like that ensuing normally as the age of the tuber increases. Appleman[3] found that heating potatoes at 40° C for 8 hours in a moist chamber hastened sprouting, though the same treatment in a dry chamber had less effect. Ajrekar and Ranadive[1] found that sound tubers of some varieties could be kept for 9 days at temperatures as high as 42° C, while others developed black heart at this temperature.

Fig. 3. Potato plants in coldframe, 25 days after planting, Aug. 21, 1927. The four rows at the right are from tubers stored at 30° C. At the left are four rows from tubers stored at 4° C.

Further evidence of the effect of storage temperature upon dormancy was obtained in another experiment during the winter of 1925. Immature tubers that were large enough to cut into four or more sets of about one ounce each were used. These were the product of the fall crop, the plants of which had been frosted on November 5 and the tubers harvested a week thereafter. They were stored in rooms at 4°, 20°–22° and 27°–30° C. No sprouts appeared on the tubers during storage at 4°; in fact, this temperature is somewhat below the minimum for vegetative growth of the potato. At 20° to 22°, sprouts appeared on the apical end of the tubers about the middle of January, and at 27° to 30° late in December. Samples were removed and planted in the greenhouse at intervals through the winter. Forty

sets were planted in each test, and a 100 per cent stand was obtained in all cases. The time for emergence of the different plantings is shown in table 6.

After 10 days in storage, the time for sprouting was the same in tubers from the three temperatures, but after 15 days there was a slight tendency to more rapid sprouting in samples from the higher temperature. This became marked at the 22-day and later periods. However, when the 66-day period was reached, there was again rather little difference in the rate of sprouting, for by this time even the tubers at 4° probably were near the end of their dormant period. It seems evident that tubers emerge from dormancy more slowly when stored at low temperatures. The differences in the time of sprout emergence as affected by temperature of the previous storage of the tubers, is shown graphically in figure 4, for the December 3 plantings. The maximum differences would probably be shown in the December 14 planting, 33 days after harvest, were that series complete. It should be remembered that the tubers used were harvested immature and are therefore not comparable to other tests, in which nearly mature tubers were used.

TABLE 6

Rate of Sprouting of Immature White Rose Potatoes, After Storage at Different Temperatures

Planting date	Average number of days to emerge		
	Stored at 4°C	Stored at 20°–22°C	Stored at 27°–30°C
Nov. 21, 10 days after harvest	85.0	84.8	85.9
Nov. 26, 15 days after harvest	88.7	84.2	78.0
Dec. 3, 22 days after harvest	81.5	73.8	60.6
Dec. 14, 33 days after harvest	66.0	43.0	No test
Dec. 24, 43 days after harvest	41.0	36.0	No test
Jan. 16, 66 days after harvest	30.9	29.8	23.5

Relation of Storage Humidity to Dormancy

It was suspected that the rather striking results secured in the temperature experiments might be due, at least in part, to the varying humidity of the storage rooms maintained at different temperatures. Appleman[3] showed that placing immature non-suberized tubers under moist conditions tended to prevent suberization and to promote earlier growth. As cold storage rooms often have a higher relative humidity than those at higher temperatures, the humidity factor may have been the cause of conflicting results of other investigators.

To determine the probable effect of the humidity factor, experiments were carried out in 1927 with two varieties at three temperaturse. Table 7 gives the results on large, nearly mature, well suberized tubers. Those samples designated in the table as "dry" are the same as those previously referred to in the temperature experiment. They were simply sacked and placed on shelves in the different temperature

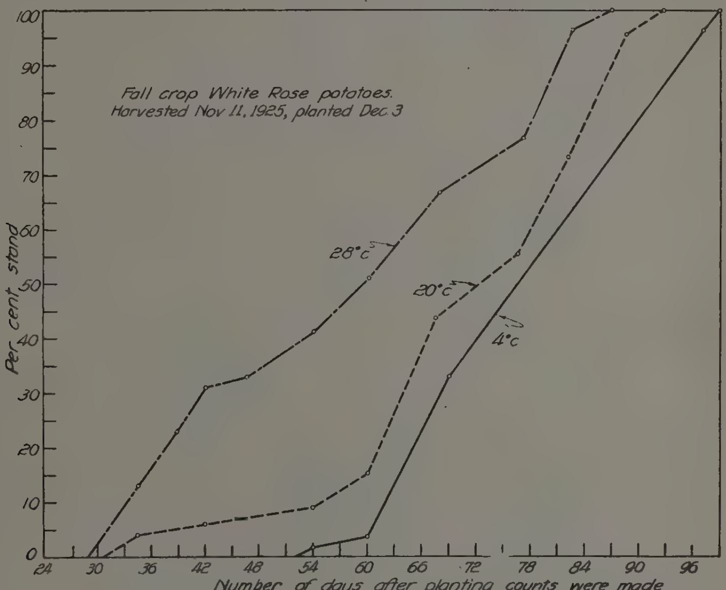

Fig. 4. Rate of sprouting of potatoes harvested Nov. 11 and planted Dec. 3, after storage at different temperatures.

chambers. The relative humidity of the air in these chambers was approximately 75 at 4°, 55 at 22°, and 60 at 30°. The samples referred to as "moist" were moistened, placed in boxes, and covered with moist sawdust. This maintained an approximately saturated atmosphere around the tubers continuously, yet with free access of air to the tubers. Different rooms were used for the dry and the moist experiments at 30°, but neither room deviated over one-half of a degree from this temperature.

Table 7 shows that at 4° and at 30°, the humidity around the potato is without effect upon the subsequent rate of sprouting; those stored under both dry and moist conditions sprouted at approximately the same rate, except the field planting of the Idaho Rural, in which

the moist sample sprouted more rapidly. There were many well developed sprouts on the tubers of this lot at the time they were removed from storage. However, at the intermediate temperature, 22° C, the moist samples in every case sprouted much more rapidly than the dry or check lots. Apparently, humidity has an important effect upon dormancy of the tuber at ordinary temperatures. Besides inhibiting further suberization of the skin, it may be that the moisture also renders the skin more permeable. These effects, however, do little

TABLE 7

EFFECT OF HUMIDITY DURING STORAGE UPON SUBSEQUENT SPROUTING OF POTATO TUBERS, SUMMER OF 1927. STORAGE PERIOD 19 DAYS

Variety	Storage temperature degrees Centigrade	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose	4° dry	65	80.4	37.7	118	36.5	34.3
	4° moist	30	100.0	41.8	120	79.0	33.4
	22° dry	120	72.3	33.6	577	61.7	34.0
	22° moist	30	90.0	25.6	120	84.2	23.9
	30° dry	60	90.0	22.3	238	63.3	24.1
	30° moist	30	100.0	22.3	117	60.7	25.7
Idaho Rural	4° dry	59	83.2	44.0	217	49.6	43.2
	4° wet	30	86.6	43.7	119	72.2	37.9
	22° dry	90	57.7	35.6	554	56.5	37.9
	22° wet	30	93.3	22.8	118	80.5	29.9
	30° dry	60	71.6	24.3	200	63.5	28.4
	30° wet	30	86.6	24.7	107	80.3	22.9

to abbreviate dormancy at 4° C, due to the limitation of the low temperature, and at 30° the effect of the moisture is not generally additive, because the high temperature itself brings about the most rapid termination of the dormant condition that is possible.

In almost every case, a higher per cent stand was obtained from the seed which had been stored under moist conditions. Just why the cut sets of the moist-stored tubers escaped decay to such an extent is not clear, but the fact is of much practical importance.

CHANGES IN THE TUBER DURING THE DORMANT PERIOD

No significant difference in the chemical composition of dormant and non-dormant potato tubers has yet been established. Appleman[3] showed that the accumulation of sugar, which occurs when tubers are stored for a few weeks at temperature near 0° C, had no causal

Fig. 5. Vegetative sprouts arising from young partly grown tubers, while still attached to the mother plant. British Queen variety, Davis, California, June, 1924.

relation to growth releasal. Neither were there significant changes in the form of the nitrogen and phosphorous compounds during the dormant period. The same worker found that active diastase and invertase were present at all stages but did not increase until sprouting began. Oxidase and catalase activity also were found to be greater at the end of the dormant period.

Moreover, while Appleman and Miller[4] found that tubers harvested at different stages of maturity differed in composition when harvested, the composition of all was about the same at the end of the

dormant period. These workers paid especial attention to the various nitrogen fractions. They found that the total non-protein nitrogen, the amide and amino nitrogen increased progressively in tubers harvested at different stages of maturity. Accordingly they consider protein hydrolysis to be one of the important changes in the ripening

Fig. 6. Section through an eye of a partly grown tuber, weighing 91 grams, harvested May 31, 1924. The meristem of the sprout is seen beneath overlapping bracts at the base of the eye depression.

of the tuber. While these nitrogenous constituents tended to come to about the same value in immature and mature tuber after four months' storage for the former and two months for the latter, this after-ripening process probably is incomplete in tubers planted in less than two months after harvest, as was the case in the writer's experiments. Newton[11] considered that the ending of the dormant period depends in part upon the activity of the proteolytic enzymes and the enzymes which convert amino to amide nitrogen.

The dormant period of potato tubers probably is not an essential part of the life cycle. Some varieties of potatoes, when grown under conditions of high temperature and abundant moisture, may form vegetative sprouts from partly grown tubers. Figure 5 shows a case of this kind in the British Queen variety. Kolterman[5] reports a similar development in Germany, following an unusual drought. Dormancy must depend upon physical and chemical conditions within the tuber.

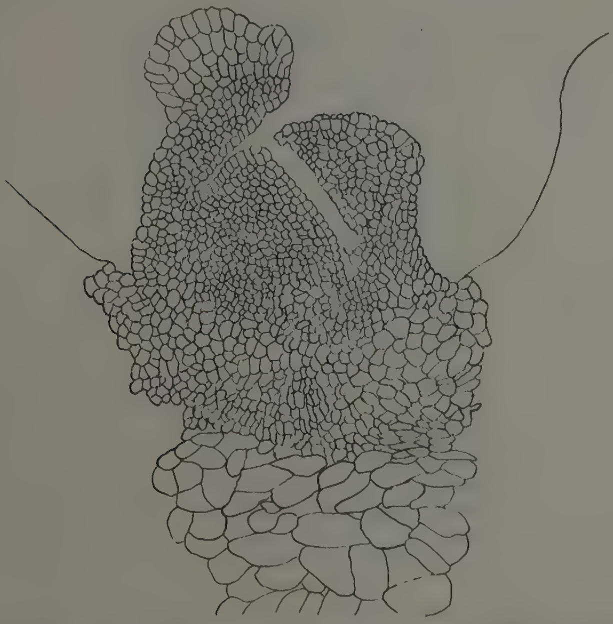

Fig. 7. Section through the eye of a large, immature White Rose tuber, just after harvest, Nov. 12, 1925. The central sprout, with its attendant bracts, is raised somewhat above the base of the eye depression.

The condition of the bud primordia in tubers at different stages of maturity and at different times in the dormant period has been investigated. Figure 6 is a section through an eye on the middle portion of a young White Rose tuber harvested May 30, 1925, and weighing 91 grams. While the bud primordia are present even in such very young tubers, sprout development has not commenced and the meristematic region is still deeply embedded in the tissue surrounding the eye. Smaller meristematic regions are visible on both sides of the bracts which envelop the central meristem. If the central

sprout is destroyed, other sprouts may be developed from the former. Figure 7 shows the apical eye of a large tuber, weighing 350 grams, harvested when nearly full grown but still immature. The sprout has already begun to form, though it is partly enclosed by the incurved bracts on each side. As the White Rose variety shows strong apical dominance, the apical sprout is much further developed than any

Fig. 8. Section through an eye of a large tuber similar to that shown in figure 7, 32 days after harvest. The young sprout shows further development in this interval. The storage was at 20° C.

other on the tuber. Figure 8 shows the apical eye of a tuber from the same lot as figure 7, but kept in storage at 20°–22° C for 32 days after harvesting. Further development of the sprout during this interval is shown. Figure 9 shows the sprout from an apical eye of a tuber from the same lot as that shown in figures 7 and 8, but kept in storage for 70 days after harvest. At this time, well developed sprouts were visible. These sections show that the bud primordia develop considerably during the late stages of tuber growth, and that some development of the sprout proceeds even during the so-called dormant

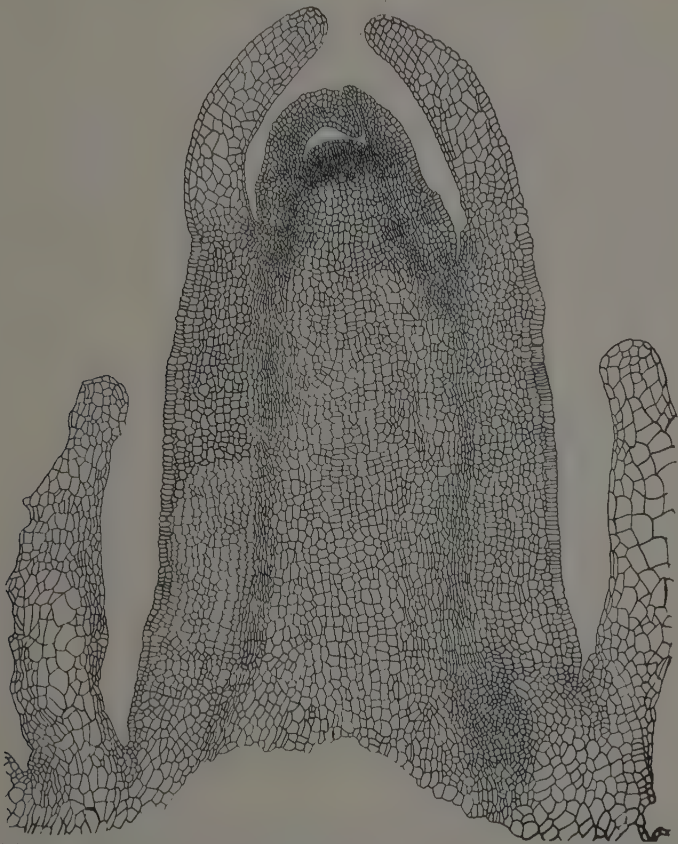

Fig. 9. Section through the sprout from an apical eye of a large tuber 70 days after harvest, and several days after planting. Elongation of the sprout becomes rapid at this stage.

period, if the tubers are stored at temperatures favorable for growth. The rate of sprout development increases toward the end of the dormant period.

Varietal Differences in Dormancy

It is known that some varieties, such as McCormick, Bodega Red, and Irish Cobbler, remain dormant longer than others. Müller-Thurgau observed that the American variety, Early Rose, had a short dormant period when grown in Germany. Wilson Popenoe, of the U. S. Department of Agriculture, found a yellow-fleshed variety in

Peru which was said to have no dormant period. Probably some of the differences observed in length of dormant period were due to differences in the stage of maturity at which the tubers were dug. Differences between the tubers within a variety may be due to the depth of the eyes. Deep-eyed tubers have a longer dormant period than shallow-eyed ones, probably because the bud primordia are so located in the former that the oxygen supply is less adequate for growth. The spindle-tuber disease has been reported to delay sprouting, but mosaic and other virus diseases have not been found to affect the dormancy of the tuber.

Several varieties grown in a spring crop (1924) were harvested June 22, when they were approaching maturity, though the tops were only partly dead. After one month's storage at 22° C, the tubers were cut and planted in the field, each plot consisting of 170 sets. The final count of the plants was made on October 13. Table 8 gives a summary of the results.

TABLE 8

VARIETAL DIFFERENCES IN THE RATE OF SPROUTING OF DORMANT POTATOES

Variety	Number of plots	Per cent stand	Average number of days to emerge
White Rose	15	62	39.0
Early Rose	1	55	39.4
Green Mountain	1	47	42.5
Idaho Rural	8	34	50.6
American Wonder	4	60	51.0
Bliss Triumph	1	32	55.0
Irish Cobbler	3	38	56.5
Garnet Chili	1	52	56.6

It appears that the White Rose and Early Rose varieties have the shortest dormant period and are the best suited, of those tested, to the practice of growing two crops a year. Thirty years ago, the Early Rose was much used in this way in the South Atlantic states, but the practice ceased when the Irish Cobbler became the leading commercial variety in that section. The longer natural dormant period in the latter variety probably made it difficult to grow two crops a year. The difference in length of dormant period noted here between Green Mountain and Irish Cobbler is in agreement with the results of Martin *et al.*,[7] who compared mature Maine-grown seed of these varieties with immature fall crop tubers from New Jersey. In the East Indies, Paravinci[12] reported that the Dutch varieties used there required a storage period of 100 days between harvest and planting in order to start growing promptly when planted.

Seed Piece Decay

Premature decay of the sets has been the chief cause of poor stands in potatoes planted during the summer at Davis. This is especially true of the field plantings. This decay is probably caused by fungi which invade the wounded cells of the cut surface. Tubers planted whole are much less subject to decay. MacMillan and Meckstroth[5] found that invasion of the potato sets by *Fusarium oxysporium* is a common cause of decay in Colorado. They found that this fungus did not invade the sets at 14° C or below, but that infection increased as the temperature was raised above this point. Ajrekar and Ranadive[1] found, in India, that bacteria and *Sclerotium* sp. were associated with the decay of potatoes at temperatures above 20° C. Probably these facts explain the prevalence of seed piece decay in plantings during hot weather. The decay usually begins in that portion of the set which comes from the center of the tuber. In that region the cells are larger and are less densely filled with starch and other substances than are the cells near the surface. Appel[2] and other workers have noted that the cut surface of a tuber ''heals'' so that a new protective layer is formed, which excludes fungi as effectively as the original periderm of the tuber. Appel found that this layer appeared 48 to 60 hours after cutting, and was completed in two additional days. Shapovalov and Edson[18] found that the new periderm or protective layer generally developed much less toward the center of a tuber than near the periphery. This may be the reason that decay of the set usually begins in the part coming from the center of the tuber.

Priestley and Woffenden[13] studied the conditions under which the healing process takes place. They find that a warm moist atmosphere with normal oxygen content is most favorable. They show that under these conditions, the cut surface is ''blocked'' in 24 to 48 hours by a deposit of fatty substances on the wounded surface. Two to five days later, a cork layer forms, as a result of rapid cell division, below the blocked surface. This results in a permanent protective layer.

With the idea that the decay of the sets in plantings during warm weather might be prevented by allowing a period for the development of the protective periderm before planting, experiments were conducted in 1925. Somewhat immature tubers were harvested July 9 and 11, samples were cut, sacked, and stored at different temperatures until July 28, when they were planted together with appropriate check lots that were cut at planting time. The results are given in table 9.

The lots cut at harvest time and stored at 1° C gave only a slightly higher percentage of stand and sprouted more slowly than the checks. Examination of the sets upon removal from storage indicated that periderm formation did not take place, to any marked extent, at 1° C. The other cut lots in storage at higher temperatures showed decay in direct proportion to the increasing temperature. Furthermore, the sprouting was much retarded in these lots, indicating that the dormant condition was prolonged, or that a secondary dormancy was

TABLE 9

EFFECT OF CUTTING IN ADVANCE UPON DECAY OF THE SETS AND RATE OF SPROUTING. STORAGE PERIOD 16 TO 18 DAYS. SUMMER, 1925

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose						
Cut July 9—stored at 1°C	30	76.6	34.0	170	65.3	39.3
Cut July 9—stored at 7°C	30	30.0	....	170	48.8	50.9
Cut July 9—stored at 13°C	30	26.7	....	175	38.3	45.5
Cut July 9—stored at 22°C	30	10.0	....	170	31.2	50.0
Cut July 8, check	30	66.6	25.7	175	64.6	32.2
Idaho Rural						
Cut July 11—stored at 1°C	30	100.0	65.7	170	47.6	58.9
Cut July 11—stored at 7°C	30	93.2	64.1	170	47.0	68.3
Cut July 11—stored at 22°C	30	10.0	....	160	15.0	65.5
Cut July 28, check	30	90.0	55.7	150	49.3	57.6

induced, by cutting in advance of planting and storing at intermediate temperatures. The cuts set stored at 7°, 13° and 22° formed a periderm over the wounded surface, which interferred with gas exchange, hence retarded sprouting, yet did not protect the sets from decay when planted in the soil.

A similar experiment was conducted in 1927, using shorter storage periods for the cut sets, which were placed in shallow trays in the different storage chambers. The results are presented in table 10.

As in the previous experiment, the sets cut in advance of planting decayed to a greater extent than those cut at planting time. The retardation of sprouting in the suberized sets is also evident. The lot stored at 4°, which became only slightly suberized, and the lot stored at 22° in wet sawdust, showed the least decay and sprouted somewhat more rapidly than the check.

No means of preventing decay of cut sets under high temperature conditions has yet been found. The suberization and healing of the cut surfaces prior to planting offers a promising line of attack for further investigation, however. Meantime, practical advantage may be taken of the fact that cut sets from medium to small tubers are less subject to decay than sets from large tubers; that tubers fully matured before harvest have less decay than those harvested immature; and tubers stored at high temperatures (22°–30°) or under moist conditions at lower temperatures, decay less when planted than tubers which have been held in cold storage. Those factors which make for more rapid sprouting also generally give a better stand.

TABLE 10

Effect of Suberization of Cut Sets upon Decay and Rate of Sprouting. White Rose Variety. Summer of 1927

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
Cut and stored for 6 days at						
4°C, dry	30	50.0	30.9	107	45.8	37.3
12°C, dry	30	40.0	40.5	114	38.6	46.5
22°C, dry	30	7.0	53.5	111	26.1	47.4
22°C, in wet sawdust	30	60.0	31.2	117	67.5	35.1
Room temperature, 15—35°C	30	0	....	100	20.0	59.8
Cut and stored for 13 days at						
4°C, dry	30	56.7	30.6	110	61.0	41 7
22°C, dry	30	7.0	69.0	110	39.0	47.6
Check—cut at planting	70	68.6	33.5	117	65.2	37.3

Summary and Conclusions

The more nearly mature potato tubers are when harvested, the shorter is the dormant period, as indicated by more rapid sprouting when they are cut and planted.

The rate at which mature tubers sprout increases rapidly with the length of storage before cutting and planting. Tubers harvested immature emerge from dormancy more slowly. The emergence from the dormant condition is a gradual, not a sudden change.

The temperature at which potatoes are stored influences the rate of emergence from the dormant condition, but previous claims as to the hastening of sprouting by cold storage are not substantiated.

Storage at 4° C may retard sprouting somewhat, compared to storage at 20° to 23°, when plantings are made in the early or middle portion of the dormant period. Storage at 28° to 30° has a marked accelerating effect upon subsequent sprouting, as compared to lower temperatures.

The humidity of the storage has little effect upon dormancy at very low temperature (4°), or at high temperature (30°). But at intermediate temperature (22°), tubers stored under moist conditions sprout much more rapidly after they are cut and planted.

The primordia of the vegetative sprouts develop during the later stages of tuber growth, as well as during the dormant period. At temperatures favorable for growth, the meristematic region is probably never entirely inactive. In the emergence from the dormant period, this activity increases greatly.

The normal duration of the dormant period for potato varieties differs, as well as their response to dormancy-breaking treatments.

One of the difficulties in growing a fall crop of potatoes in California is the prevalence of seed piece decay when the planting is made during hot weather. The amount of decay is increased and the dormancy of the sets is prolonged by cutting several days before planting and allowing the cut surface to become suberized.

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EFFECTS OF CHEMICAL TREATMENTS ON DORMANT POTATO TUBERS

J. T. ROSA[1]

Foreword

The treatment of dormant tubers with various substances to hasten sprouting has been extensively investigated, but as yet no method of treatment has been adopted by commercial growers. While it is believed that such matters as tuber maturity, storage temperature, and the normal length of dormant period for the variety are important factors, the use of chemical stimulants for seed treatment is also likely to be of practical value in many cases. The word "stimulant" is used to designate substances which are probably not used as nutrients, yet are capable of accelerating the plants' activities.

In this paper will be presented the results of a number of experiments, designed largely to determine effective methods for the stimulation of sprouting in dormant seed potatoes. Studies concerning the effect of such treatments upon the metabolism of the tuber are under way, but the discussion of this phase of the work will not be entered upon at this time.

Previous Work with Chemical Treatments

McCallum[(4)] found that sprouting was hastened by exposing potatoes to the fumes of ethyl bromide, carbon tetrachloride, ammonia, and gasoline, at the rate of ½ to 1 cc. in a 5-liter chamber for 24 hours. He also obtained positive results with ethyl bromide and with ethylene chloride. Appleman[(1)] found that treatment with hydrogen peroxide gave positive results. Rosa[(5)] has reported hastened sprouting by soaking the cut sets in solutions of various salts before planting; 0.5 molar solutions of sodium and potassium nitrates for periods ranging from 10 minutes to one hour, 0.02 mol. potassium permanganate, .005 mol. ferric chloride, and .05 normal hydrochloric acid for

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one hour, were all found to hasten sprouting, especially when the tubers were in the middle or later part of their dormant period. However, these materials were found to be somewhat toxic to the tissues of the tubers. While this had no bad effects when the sets were planted in fall, winter, or spring, when soil temperatures were low, there did result an increased amount of seed piece decay when the planting was in mid-summer, with high soil temperatures prevailing. Denny[(2)] tested 224 different chemicals on potatoes. He obtained striking results in hastened sprouting with ethylene chlorhydrin and ethylene dichloride applied in various way, and with sodium, potassium, and ammonium thiocyanate solutions. Even dormant tubers of the Irish Cobbler variety were caused to sprout in one month after planting by treatment with 2 or 3 per cent solutions of the thiocyanates. Denny also obtained favorable results with carbon bisulfide and some other substances.

Three varieties, White Rose, Idaho Rural, and Irish Cobbler, have been used in the writer's experiments. Tubers were grown at Davis in the regular spring crop, harvested just before the plants died, and placed in storage at 22° to 23° C. The storage period in most cases was three to four weeks. Plantings were made in sand in the coldframe, and in soil in the field. Counts were made every few days of the sprouts, as they emerged above the surface of the soil.

Experiments with Ethylene

In 1925, two experiments were carried out, to determine the effect of ethylene gas on germination of potatoes. In the first test, three varieties were used. The tubers were harvested June 20, when they were approaching maturity. They were stored in a dry cellar at about 22° C. The samples to be treated for four weeks were placed in the gas chambers on June 24 and treatment was continued until July 23. The samples to be treated for two and three weeks were held in the cellar with the checks until the proper date, and then removed to the gas chamber. On July 26 (36 days after harvest) the tubers were cut and planted in the coldframe. The chambers were about 400 liters capacity, and were not absolutely airtight. Sufficient ethylene gas was applied each day to give a concentration of 1 : 400 in one chamber and 1 : 2200 in the other. The chambers were opened for a few minutes each day for ventilation. As the results with the two concentrations paralleled each other, they are averaged in table 1.

With these three varieties, 4 weeks' treatment with ethylene resulted in more rapid sprouting than was the case with the untreated checks. The difference was slight with the White Rose variety, which apparently had nearly reached the end of its dormant period (having been held at 22° for 36 days). The lots exposed to ethylene for 3 and 2 weeks gave in every case a slower rate of germination than the checks. The reason for this fact may be the known toxicity of ethylene to vegetative growth, as the sprouts may have started slightly on the 2- and 3-week lots before they were placed in ethylene. These lots were held in the cellar for 1 and 2 weeks, respectively, before

TABLE 1

Effect of Ethylene upon Sprouting. July–September, 1925

Treatment	Number of sets	Per cent stand	Average number of days to emerge	Average number of stems per set
White Rose				
Ethylene, 4 weeks	60	95.0	28.3	1.51
Ethylene, 3 weeks	60	93.4	39.6	1.38
Ethylene, 2 weeks	60	95.0	39.0	1.28
Untreated	90	84.5	30.8	1.20
Idaho Rural				
Ethylene, 4 weeks	60	75.0	22.2	1.18
Ethylene, 3 weeks	60	76.6	38.9	1.15
Ethylene, 2 weeks	65	87.7	43.4	1.09
Untreated	90	74.7	30.7	1.12
Irish Cobblers				
Ethylene, 4 weeks	29	93.2	42.0	1.30
Ethylene, 3 weeks	30	93.2	70.5	1.14
Ethylene, 2 weeks	29	86.3	56.8	1.12
Untreated	60	73.4	50.0	1.23

being placed in the gas chamber. All of the ethylene-treated lots gave a higher percentage of stand than the checks, and a slight increase in the average number of stems arising from each set.

A second experiment with ethylene was performed in the fall of 1925, fully matured, spring crop tubers harvested July 30 being used. Lots of 30 to 40 sets each were planted in the greenhouse at intervals after harvesting. The untreated tubers were stored at 20° to 23° C, while those treated with ethylene were kept at the same temperature in a chamber with ethylene at 1:800 concentration applied daily. The results are given in table 2.

With the White Rose variety, the plantings made after 6 and 15 days show a marked hastening of the sprouting of tubers exposed to ethylene. The later plantings showed little difference, however, as the

tubers had evidently passed their dormant period. In this case, fully mature tubers of a variety having only a short dormant period were involved. With the Idaho Rural, the ethylene-treated lots sprouted more rapidly at all stages, though the gain over the untreated checks was greatest at the 15 and 28-day periods. In all cases, there was a tendency for the number of stems per set to increase as the period between harvest and planting was lengthened. This was most marked with the lots stored in ethylene gas. Rosa[5] has previously called attention to the increase in number of stems, in potatoes planted after the end of the dormant period, compared to those which are still somewhat dormant.

TABLE 2

Effect of Ethylene upon Sprouting, with Reference to the Stage of Dormancy. Fall, 1925

	Untreated			Ethylene 1:800		
	Per cent stand	Average number of days to emerge	Average number of stems per set	Per cent stand	Average number of days to emerge	Average number of stems per set
White Rose						
Planted after						
6 days' storage	67	55.9	1.00	100	36.9	1.07
15 days' storage	77	38.2	1.14	97	33.2	1.00
28 days' storage	100	20.0	1.04	100	20.5	1.03
39 days' storage	100	18.2	1.23	100	17.0	1.36
55 days' storage	100	21.2	1.17	100	17.0	1.58
Idaho Rural						
6 days' storage	63	77 3	1 00	90	71.4	1.00
15 days' storage	45	60.8	1.00	83	29.5	1.21
28 days' storage	100	38.4	1.03	100	27.1	1.14
39 days' storage	100	30.2	1.17	100	22.0	1.21
55 days' storage	100	29.7	1.23	100	16.5	1.61

Experiments with Ethylene Chlorhydrin on Large Tubers

This substance is obtained commercially as a 40 per cent solution of the gas in water. The gas volatilizes rather slowly when the solution is exposed to air. It was used in the three ways suggested by Denny. (1) Fumigating whole tubers in a closed chamber for 24 hours, using 1 cubic centimeter to each liter of space in the chamber. (2) Soaking cut sets in a one-half per cent solution for one hour. (3) Dipping the cut sets in a 3 per cent solution (or stronger) for a moment, then placing them in a closed container overnight.

The tubers used in the 1926 tests were harvested June 19, in a slightly immature condition. They were stored at 23° C until July 13, a period of 24 days, except for the four lots which were treated and planted 14 days after harvest. The tubers should have been still in the dormant condition at the end of this period. The results are given in table 3.

TABLE 3

EFFECT OF ETHYLENE CHLORHYDRIN UPON SPROUTING OF CUT SETS FROM LARGE MATURE TUBERS. SUMMER, 1926

	Coldframe plantings			Field plantings		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose, planted 14 days after harvest.						
Lot No.						
52. Untreated	60	77.4	47.8	0	....	....
50. Gassed 24 hours	30	80.5	27.5	0	....	....
49. Cut sets in 1% solution for 1 hour	30	66.6	37.5	0	....	....
51. Cut sets dipped in 3% solution	30	19.3	41.8	0	....	....
White Rose, planted 24 days after harvest.						
57. Untreated	60	74.9	34.3	241	50.6	38.5
55A. Gassed 24 hours at harvest time	30	73.4	24.4	43	46.5	30.1
53. Gassed 24 hours 2 weeks after harvest	30	70.0	23.9	82	72.0	26.8
61. Gassed 24 hours at planting time	30	86.6	20.9	98	49.0	39.4
60A. Cut sets in ½% solution for 1 hour	30	86.6	25.6	76	53	31.8
60B. Same solution as in 60A, second lot	30	83.2	23.2	0	....	....
60C. Same solution as in 60A, third lot	30	66.6	21.6	0	....	....
63. Cut sets dipped in 3% solution	30	30.0	19.6	69	36	34.8
91. Cut sets dipped in 4½% solution	0	....	....	94	24.5	39.5
Idaho Rural, planted 24 days after harvest.						
68. Untreated—large tubers, cut	161	76.8	34.6	399	61.6	51.1
55B. Gassed 24 hours at harvest	30	56.6	21.6	104	68.0	29.7

The White Rose tubers treated and planted two weeks after harvest (lots 49, 50, and 51) showed marked hastening of sprouting, especially in lot 50, which was treated by method 1. Those treated by method 3, in a 3 per cent solution, were much injured.

Lots 55A, 53, and 61, planted 24 days after harvest, were medium to large tubers, treated according to method 1 just after harvesting, 2 weeks after harvesting, and just before planting. Denny suggested that the toxic effects of the treatment upon the tubers may be lessened by treating some days in advance of cutting and planting. The results in coldframe and field plantings do not agree entirely. In the former, the treatment was most effective when given just before planting,

while in the field the highest percentage of stand and the most rapid sprouting occurred in the lot treated two weeks after harvest. It is apparent that the treatment at all three periods had considerable effect in hastening sprouting, with no evidence of toxic effects. It may be concluded that seed tubers can be safely treated at any time between harvest and planting. Figure 1 shows the marked difference

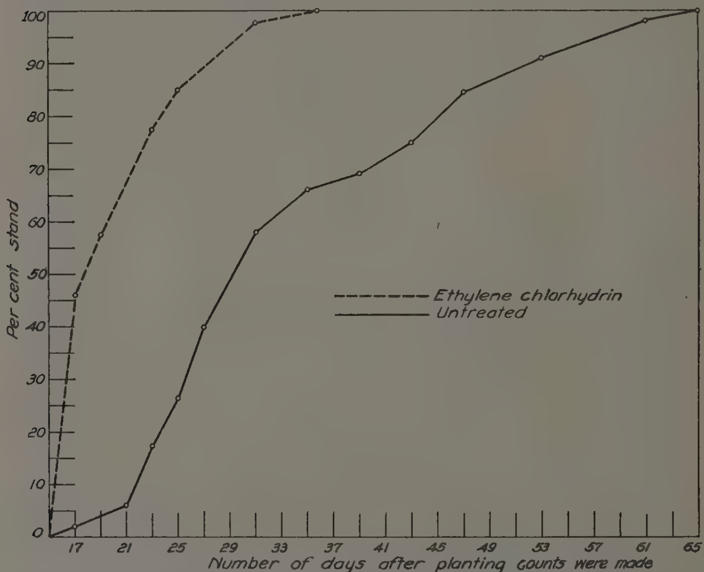

Fig. 1. The rate of sprout emergence of White Rose sets planted 24 days after harvest. Lot 57, untreated, and lot 61, treated with ethylene chlorhydrin just before planting, by method 1.

in rate of sprout emergence between untreated sets and those treated with ethylene chlorhydrin at planting time by method 1. While the treatments with ethylene chlorhydrin hasten sprouting, they do not, on the average, give a materially higher percentage of germination than no treatment, when cut sets from large tubers are considered. This is due, as in all the other experiments under high temperature conditions, to the decay of a large number of sets soon after planting.

With the Idaho Rural variety, large tubers treated with ethylene chlorhydrin at harvest time according to method 1 gave a very marked acceleration of sprouting, there being an average gain of 13 days in the coldframe planting and 31.4 days in the field planting. However,

the percentage of the sets planted that produced plants was no larger than in the untreated lot.

Lots 60A, 60B, and 60C were treated according to method 2, the same solution being used to treat the three lots successively. The stimulation to sprouting was marked in all cases. Lots 63 and 91, treated according to method 3, again showed decided toxicity from this treatment, most of the seed pieces decaying.

On the whole, the results show that ethylene chlorhydrin is effective in hastening the sprouting of dormant potatoes, thus confirming

TABLE 4

EXPERIMENTS WITH ETHYLENE CHLORHYDRIN USED ACCORDING TO METHOD 1, ON LARGE TUBERS. SUMMER, 1927

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Averag number of days to emerge
White Rose						
Gassed 24 hours, 1 cc per liter	30	100.	21.7	107	73.8	25.4
Gassed 24 hours, 0.75 cc per liter	30	86.6	21.1	114	73.7	23.8
Gassed 24 hours, 0.5 cc per liter	30	76.6	22.4	120	44.2	27.5
Gassed 24 hours, 0.25 cc per liter	30	90.0	23.9	118	49.2	27.5
Checks—not treated	120	72.3	33.6	577	61.7	34.0
Idaho Rural						
Gassed 24 hours, 1 cc per liter	30	80.0	33.3	117	68.4	31.9
Gassed 24 hours, 0.75 cc per liter	30	83.3	29.4	107	59.8	30.9
Gassed 24 hours, 0.5 cc per liter	30	86.6	33.2	80	27.5	33.3
Gassed 24 hours, 0.25 cc per liter	30	70.0	32.0	86	41.0	38.9
Checks—not treated	90	57.7	35.6	554	56.6	37.9

Denny's work. However, treatment with this material does not prevent decay of the seed pieces under high temperature conditions, and in treatment by method 3, even increases it. This factor would probably not be so serious in cool localities or in winter and spring plantings. Of the various methods of using ethylene chlorhydrin, method 1 seems most likely to be suitable for commercial use.

Further experiments with ethylene chlorhydrin were conducted in 1927, to determine the optimum concentration for treatment by method 1. A tight chamber, 4 × 4 × 5 feet in size, was used. The tubers were placed in shallow boxes stacked one above the other with strips between. An electric fan blowing directly upon a pan containing the ethylene chlorhydrin hastened its volatization. The treatments were made at 20° to 24° C. Denny[3] states that the dosage can be

reduced to .35 cc. per liter of space, when the treatment is performed in such a room, with a fan. The results obtained on the large tubers treated by this method are given in table 4. The treatments were made 10 or 11 days after harvesting upon tubers stored in a dry cellar at 22° C. The tubers were cut and planted 10 days later.

The White Rose responds somewhat more markedly to treatment with ethylene chlorhydrin than does the Idaho Rural, but both varieties show a marked stimulation of sprouting from treatment with this material. The sprouting is most rapid with 1 cc. and with 0.75 cc. per liter of space, the latter concentration being slightly more effective than the former. The lower concentrations, while exerting considerable effect, are markedly less stimulating under the conditions of these experiments. There was no evidence of toxic effects at any concentration, the percentage of stand being in most cases better than that of the checks.

Experiments with Ethylene Chlorhydrin upon Small Tubers

Because so many cut sets decay when planted in the field during summer, and since uncut tubers are not so subject to decay, it was thought that it might be advisable, from the practical point of view, to plant small tubers whole. Earlier experiments, however, had shown that sets of this kind sprouted very slowly. Experiments were made in the summers of 1926 and 1927 to determine the effect of various chemical treatments on such tubers. The results with ethylene chlorhydrin are given in table 5. Tubers, harvested mature, about 1.5 ounces in average weight, were treated according to method 1 at harvest time and just before planting, respectively.

Treatment with ethylene chlorhydrin in most cases increased the per cent stand, as determined by the last count at the end of the growing season, but the speed of sprout emergence was increased only slightly. In the latter respect, however, the tests of 1927 with both White Rose and Idaho Rural show distinctly more marked effects from treatment immediately after harvest than from treatment in the middle of the storage period or just before planting. The lesser degree of suberization of the periderm at harvest time than after storage for a period, may permit the ethylene chlorhydrin to enter the tissues of the tuber more effectively. The fact remains, however, that small tubers planted whole do not respond vigorously to the same treatment that proved very effective on large tubers of the same varieties and

degree of maturity, but which were cut before planting. Similar results were obtained with ethylene dichloride and ethyl bromide, and are shown graphically in figure 2. Cutting is itself a mild dormancy-breaking treatment, as shown by Appleman.[1] Schlumberger[6] considers wound-irritation, as induced by cutting the tuber or by injury in various other ways, to be of great importance in stimulation effects. Such effects are lacking when the tubers are planted whole.

TABLE 5

EXPERIMENTS WITH ETHYLENE CHLORHYDRIN UPON SPROUTING OF SMALL TUBERS PLANTED WHOLE, 21 DAYS AFTER HARVEST

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose, 1926						
Lot 56A. Gassed at harvest	30	53.3	52.8	107	74.0	72.7
Lot 62. Gassed at planting	30	60.0	60.5	78	74.0	74.7
Lot 58A. Check—not treated	30	13.3	64.7	85	42.0	81.4
White Rose, 1927						
Lot 67. Gassed at harvest	0	....	....	102	90.0	43.4
Lot 71. Gassed after 10 days	0	....	....	115	90.0	49.6
Lot 74. Gassed at planting	0	....	....	115	86.0	50.6
Lot 38. Check—untreated	0	....	....	120	85.0	61.7
Idaho Rural, 1926						
Lot 56B. Gassed at harvest	30	56.6	52.4	98	85.0	70.9
Lot 56B. Check—untreated	30	83.2	56.6	109	82.0	81.1
Idaho Rural, 1927						
Lot 68. Gassed at harvest	0	....	....	117	71.8	52.8
Lot 72. Gassed after 10 days	0	....	....	120	83.3	61.5
Lot 75. Gassed at planting	0	....	....	120	74.2	65.0
Lot 39. Check—untreated	0	....	....	120	76.7	65.5

EXPERIMENTS WITH SODIUM THIOCYANATE

Denny[2] reported favorable results from soaking cut sets for one hour in 3 per cent solutions of sodium thiocyanate, when the tubers were deeply dormant, and in a 2 per cent solution for one hour or in a 1 per cent for two hours, as they approached the end of the dormant period. Experiments were conducted in the summer of 1926 to determine the suitability of sodium thiocyanate for treatment of potatoes under California conditions. Ammonium thiocyanate was used in 1927. Large tubers of the White Rose variety, harvested quite immature, and smaller but mature tubers of the Idaho Rural and

Irish Cobbler were used. The difference in maturity and in tuber size may explain the less injurious effects secured with the last two varieties. It has been the general observation in all of these experiments that seed piece decay is more prevalent in sets cut from large tubers, especially when they are harvested immature. Table 6 gives the results.

TABLE 6

EFFECT OF SODIUM THIOCYANATE AND AMMONIUM THIOCYANATE UPON SPROUTING

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose, 3 weeks after harvest.						
Lot 57. Untreated	90	67.8	30.2	98	46.7	41.4
Lot 37. 2 per cent solution of NaCNS for ½ hour	30	70.0	35.4	89	50.6	35.3
Lot 38. 2 per cent solution of NaCNS for 1 hour	30	66.6	33.0	105	63.8	34.8
Lot 39. Same, second lot	30	32.0	....	0	....	....
Lot 40. Same, third lot	30	16.7	....	0	....	....
Lot 41. Same, fourth lot	30	3.3	....	0	....	....
Lot 42. 3 per cent solution of NaCNS for ½ hour	30	26.7	28.7	106	46.2	36.8
Idaho Rural, 2 weeks after harvest.						
Lot 48. Untreated	30	90.6	45.8	0	....	....
Lot 47. 2 per cent solution of NaCNS for 1 hour	30	74.2	43.6	0	....	....
Idaho Rural, 3 weeks after harvest.						
Lot 67. Untreated	161	76.8	34.6	399	61.6	51.1
Lot 34. 2 per cent solution of NaCNS for 1 hour	30	76.6	28.5	116	77.6	32.3
Irish Cobbler, 24 days after harvest (1927).						
Lot 102. 2 per cent solution of NH_3CNS for 1 hour	35	31.6	33.5	120	21.6	38.0
Lot 103. 2 per cent solution of NH_3CNS for ½ hour	35	48.6	41.8	120	37.5	44.1
Lot 104. 1 per cent solution of NH_3CNS for 1 hour	34	64.7	45.4	0	....	....
Checks—untreated	60	63.3	37.2	186	78.6	36.2

Soaking the White Rose sets in 2 per cent sodium thiocyanate for one-half hour and for one hour had little effect upon the percentage of stand or upon the time required for sprouting. The Idaho Rural variety treated in a 2 per cent solution for one hour, two weeks after harvest, showed little effect, but this treatment a week later gave marked hastening of sprouting without toxic effects. Treatment in 3 per cent solution for only one-half hour resulted in very severe injury to the sets. With the Irish Cobbler, treatment in 2 per cent

solutions of ammonium thiocyanate was very toxic, the amount of seed piece decay being much increased. The 1 per cent solution was not toxic, but had no effect upon the rate of sprouting. In other tests, in the greenhouse during the winter, the 3 per cent solution gave marked stimulation without toxic effects. With this material, as with others previously tested in California, the danger of toxic effects is greatly increased in hot weather. The thiocyanates, like some other substances, may be used safely in the cooler parts of the season, but cause much decay of the sets, with resultant poor stands, under high temperature conditions.

Lots 38, 39, and 41, which were treated successively in the same solution, show a decreasing stand, indicating increased toxicity of the thiocyanate solution. This may be due to differential absorption of ions by the potato tissue, thus altering the composition of the solution. Apparently sodium thiocyanate solution cannot be used repeatedly in treating potatoes.

Other Chemical Treatments

Several chemicals besides those previously discussed have been tested from time to time, to determine their effect upon sprouting. Since time and concentration factors are involved, as well as the stage of dormancy of the tuber and the temperature at which the plantings are made, this is a slow and laborious process. In the winter of 1924–25, tests were made in the greenhouse of immature White Rose tubers of the fall crop harvested November 15. Table 7 gives the results of some treatments which had positive results.

The immature tubers treated only 2 days after harvesting on November 17 showed marked stimulation by ethyl bromide. Whole tubers (which were cut before planting) of the stage of maturity used in these tests cannot be safely treated for more than 15 minutes at the concentration employed. Cut sets did not respond as well as those treated whole and then cut for planting. The time and concentration factors should both be much lower where cut sets are to be treated.

Potassium dichromate was mildly stimulating, but was toxic at the higher concentrations, the tissue around the eyes being chiefly affected, and not the pith parenchyma (inner medulla) as is the case with most toxic substances. Potassium ferro- and ferricyanide, tested at this time in concentrations ranging from .05 mol. to .25 mol. solutions for one hour, showed both forms of injury, and no stimulating effects.

In the tests planted January 10, the tubers were nearing the end of the dormant period. Whole tubers were treated with the various materials, then cut and planted at once. Ethyl acetate and ether showed considerable stimulation, while carbon tetrachloride and gasoline had less effect. The last two substances, tested at higher concentrations, proved toxic. Chloroform was decidedly toxic, and

TABLE 7

MISCELLANEOUS CHEMICAL TREATMENTS IN WINTER OF 1924–25

Date and treatment	Number of sets	Per cent stand	Average number of days to emerge	Injury to sets
ov. 17. Ethyl bromide on whole tubers, cut for planting.				
4 cc per liter for 15 minutes	19	84	31.4	slight
4 cc per liter for 30 minutes	20	60	31.4	severe
4 cc per liter for 60 minutes	17	35	....	very severe
Untreated	35	90	92.0	....
Ethyl bromide on cut sets.				
2 cc per liter for 2½ minutes	20	100	49.7	none
2 cc per liter for 5 minutes	19	100	43.8	none
2 cc per liter for 7½ minutes	19	95	54.2	very slight
2 cc per liter for 10 minutes	17	94	50.5	slight
2 cc per liter for 20 minutes	19	79	44.3	severe
Dec. 10. Potassium dichromate—cut sets.				
Soaked 1 hour in .01 mol. solution	18	67	59.5	eyes injured
Soaked 1 hour in .005 mol. solution	17	88	66.9	none
Soaked 1 hour in .001 mol. solution	17	100	53.4	none
Untreated	36	100	70.0	....
Jan. 10. Whole tubers, cut for planting.				
Ether, 2 cc per liter for 1 hour	21	100	22.9	none
Ethyl acetate, 2 cc per litre for 1 hour	20	100	21.4	none
Chloroform, 2 cc per liter for 1 hour	17	47	....	severe
Carbon tetrachloride, 2 cc per liter for 1 hour	18	100	25.1	none
Gasoline, 4 cc per liter for 1 hour	17	100	25.2	none
Untreated	21	100	29.4	....

bromine and chlorine gases, which were tested at one-half and at one hour exposures, were very toxic.

In the summer of 1925, tests were made on tubers harvested nearly mature, the results of which are given in table 8. Whole tubers were exposed to ethyl bromide for 15 minutes at the same concentration as before. This treatment, upon well suberized tubers after one month's storage gave little stimulation; the results were not so striking as in former tests, with immature tubers. Small tubers treated 10 days after harvest for 15, 30, and 60 minutes, and planted without cutting, showed very little stimulation with the time and concentration used

TABLE 8

EFFECT OF MISCELLANEOUS CHEMICALS UPON SPROUTING. SUMMER, 1925
(Coldframe planting—30 sets in each lot)

	White Rose		Idaho Rural	
	Per cent stand	Average number of days to emerge	Per cent stand	Average number of days to emerge
Large tubers 1 month after harvest.				
Ethyl bromide 15 minutes	97	27.8	97	44.0
Untreated	84.5	30.8	72	37.3
Small tubers 10 days after harvest.				
Ethyl bromide for 15 minutes	0	....	97	76.6
Ethyl bromide for 30 minutes	0	....	80	71.0
Ethyl bromide for 60 minutes	0	....	82	70.9
Untreated	0	....	93	80.0
Tubers 17 days after harvest—cut sets.				
Sodium nitrate, .5 mol. solution, soaked 10 minutes	90	21.0	77	31.2
Sodium nitrate, .5 mol. solution, soaked 20 minutes	87	22.8	63	27.9
Sodium nitrate, .5 mol. solution, soaked 30 minutes	63	23.5	27	27.0
Untreated	84	33.5	90	55.7
Potassium permanganate, .02 mol. solution, soaked 15 minutes	77	33.1	77	36.5
Potassium permanganate, .02 mol. solution, soaked 30 minutes	70	29.0	72	37.0

here. Subsequent experiments with ethyl bromide, however, using 0.25 cc. to 0.5 cc. per liter for 24 hours upon whole tubers, gave a marked stimulation to sprouting, without toxic effects.

Treatment of cut sets 17 days after harvest in 0.5 mol. solution of sodium nitrate gave a marked stimulation to sprouting, especially in Idaho Rural variety. Under the high temperatures prevailing when these tests were made, even a 20 minute soaking in nitrate solution caused some injury, and a 30 minute one was very toxic. Potassium

TABLE 9

EFFECT OF MISCELLANEOUS CHEMICALS UPON SPROUTING. SUMMER, 1926

	Coldframe plantings			Field plantings		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
Untreated	161	76.8	34.6	399	61.6	51.1
Ethylene dichloride, whole tubers	45	68.9	30.2	106	73.0	44.3
Ethylene dichloride, cut sets	30	96.7	33.2	96	51.0	47.6
Sodium nitrate, 0.5 mol. for 20 minutes	77	78.3	29.0	203	69.0	42.1
Ethylene 1:2000, gassed for 3 weeks	30	83.2	27.5	99	66.0	45.3
Propylene 1:2000, gassed for 3 weeks	60	83.3	27.5	182	44.0	44.8

permanganate at 0.02 mol. concentration up to 30 minutes soaking proved to be mildly stimulating and non-toxic, but longer treatment or higher concentrations of this substance proved injurious in other tests. The permanganate is reduced rapidly by contact with cut potato sets.

In the summer of 1926 ethylene dichloride, sodium nitrate, ethylene and propylene were tested upon Idaho Rural tubers harvested nearly mature and stored for 24 days. The results are given in table 9.

Ethylene dichloride was one of the substances which gave especially good results in Denny's experiments. In the tests here, it was used at the rate of 0.114 cc. to a liter of space, for 24 hours on whole tubers which were afterwards cut for planting, and half this dosage for 15 hours on cut sets. It proved to be moderately stimulating to sprouting but did not prevent the usual large percentage of seed piece decay. The same can be said for the other substances tested.

Further Experiments with Ethylene Dichloride

Further experiments were made in the summer of 1927 with ethylene dichloride upon Idaho Rural and Irish Cobbler. These two varieties had been previously found not to respond as vigorously to ethylene chlorhydrin as does the White Rose. The tubers used were harvested nearly mature and stored in a dry room at 22° for three weeks before planting. They were, accordingly, well suberized at the time the treatments were made, which was two weeks after harvest and one week before planting. The treatment was by the vapor method, the proper amount of liquid ethylene dichloride being placed with the dry, whole tubers in a chamber which was kept closed for 24 hours. The tubers were of two classes, large tubers that were subsequently cut for planting, and tubers of one to one and one-half ounce weight, which were planted whole. The results are given in table 10.

Considering first the effect of ethylene dichloride upon large tubers, it appears that there are no toxic effects with either of the concentrations used, since the percentage of stand is in all cases higher than in the untreated lots. It is also evident that this material exerts a marked stimulating effect upon both varieties tested. The evidence is not conclusive as to which concentration is most effective, but the higher concentration appears to be somewhat more so.

In the tests with small tubers planted whole, some increased stand resulted in every case, from treatment with ethylene dichloride, due

TABLE 10

EFFECT OF ETHYLENE DICHLORIDE UPON SPROUTING OF CUT SETS FROM LARGE TUBERS, AND OF SMALL WHOLE TUBERS. 1927

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
Idaho Rural, large tubers.						
Lot 98. 0.2 cc per liter	30	83.3	43.8	97	75.3	42.2
Lot 99. 0.4 cc per liter	30	96.7	25.5	111	68.5	31.2
Checks—untreated	90	57.7	35.6	554	56.5	37.9
Irish Cobbler, large tubers.						
Lot 100. 0.2 cc per liter	30	100.0	30.8	115	83.5	24.1
Lot 101. 0.4 cc per liter	30	96.7	29.1	115	81.7	26.8
Checks—untreated	60	80.0	37.2	136	78.6	36.2
Idaho Rural, small tubers.						
Lot 87. 0.2 cc per liter	0	......	......	98	75.5	57.1
Lot 88. 0.4 cc per liter	0	......	......	102	90.2	53.3
Check, untreated	0	......	......	120	76.7	65.5
Irish Cobblers, small tubers.						
Lot 93. 0.2 cc per liter	0	......	......	100	88.0	48.3
Lot 94. 0.4 cc per liter	0	......	......	120	83.4	50.0
Check—untreated	0	......	......	105	71.4	65.0

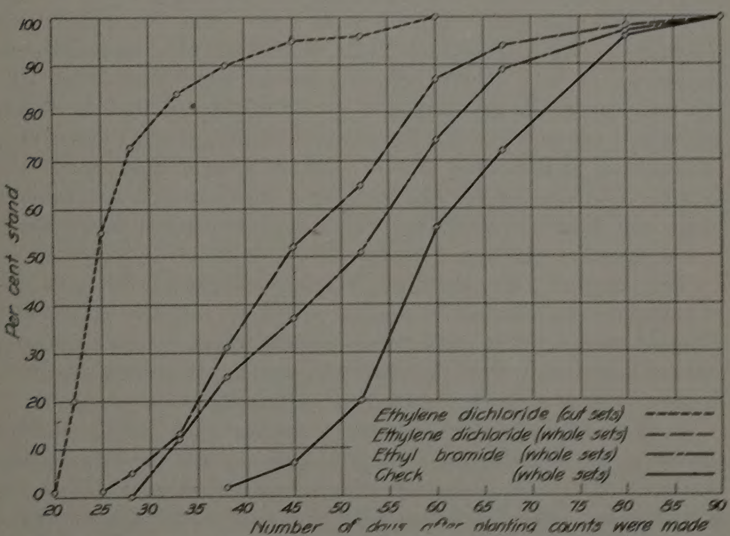

Fig. 2. The rate of sprout emergence of small tubers planted whole, untreated and after treatment with ethylene dichloride and ethyl bromide, compared to cut sets from large tubers treated with ethylene dichloride. Irish Cobbler variety.

to the fact that more plants appeared above ground before the end of the growing season. Furthermore, there is some increase in the rate of sprouting, though here as in other experiments with tubers planted whole, the stimulatory effect is less than in tubers cut before planting. Whereas the treatment of large tubers reduced the average time required for emergence by about 30 per cent, with small whole sets this period was reduced only 15 per cent in Idaho Rural, and 26 per cent with Irish Cobbler. Figure 2 shows that whole tubers planted in the field, after treatment with ethylene dichloride and ethyl bromide, sprout more rapidly than untreated whole tubers, yet they lag considerably behind cut sets of the same variety.

Summary

Ethylene, in concentrations of from 1:400 to 1:2200 of air, exerted a mild effect upon the hastening of sprouting of dormant, nearly matured, moderately suberized tubers placed in the gas chamber at harvest time and held there for four weeks.

Ethylene hastened the sprouting of fully matured White Rose tubers after treatment for only six days, while the Idaho Rural variety showed maximum stimulation after treatment for fifteen days.

Ethylene chlorhydrin proved to be a very effective material for treating the White Rose and Idaho Rural varieties, especially the former, at 14- and 21-day periods after harvest. Treatment with this material by the gas method on whole tubers and by soaking cut sets in a ½ per cent solution for one hour, showed marked stimulation to sprouting without toxic effects. A third method, dipping cut sets in 3 per cent or stronger solutions for a moment, then storing over night in a closed container, resulted in a great increase in the decay of the sets after planting.

Treatment of large tubers with ethylene chlorhydrin by method 1, at different stages during the storage period did not give consistently different results. With small tubers planted whole, however, the most marked stimulation effect was observed when the treatment was given at harvest time, when the tubers were only moderately suberized.

Tests to determine the optimum concentration of ethylene chlorhydrin to use according to method 1, indicate that for large tubers that are well suberized, the most effective concentration is 0.75 cc. per liter of space. This is for treatment in a room at 20°–25° C, with a fan to hasten the volatilization of the gas, as well as to insure uniform distribution.

Sodium thiocyanate and ammonium thiocyanate, especially the latter, were found to be toxic to cut sets soaked in 2 and 3 per cent solutions, when planted during hot weather. One per cent solution was non-toxic and had little or no stimulating effect.

Ethyl bromide was found to be an effective material for hastening sprouting, but the proper concentration for treatment varies widely, according to the maturity and degree of suberization of the tuber skin. This substance was not found to be satisfactory for the treatment of cut sets.

Sodium nitrate was moderately effective as a stimulant, when cut sets were soaked in an 0.5 mol. solution. However, this material is likely to cause excessive decay of the sets when the planting is made in hot weather.

Ethylene dichloride was very effective, especially on the Irish Cobbler variety, when used either as a gas on whole tubers or in solution for cut sets. The former method seems to be the most practical one. The optimum concentration probably lies between 0.2 and 0.4 cc. per liter of space, for a 24-hour exposure on large tubers.

Experiments with ethylene chlorhydrin, ethylene dichloride, and ethyl bromide upon small mature tubers that are planted whole, indicate that treatment of this class of tubers is much less effective than similar treatments upon large tubers that are cut before planting. It is not known whether this difference is due to a naturally longer and more profound dormancy in small tubers, or to the additive stimulation effect of cutting upon tubers previously treated with stimulants. From the practical viewpoint, however, of elimination of seed piece decay and of stimulating prompt sprouting of potatoes planted during midsummer, there is considerable promise for combinations of storage methods known to hasten sprouting with the use of chemical stimulants upon small tubers.

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